

OXYGEN ENRICHING APPARATUS, CONTROLLER, AND RECORDING MEDIUM

BACKGROUND OF THE INVENTION

1. Field of the Invention:

The present invention relates to an oxygen enriching apparatus (or oxygen concentrator) capable of producing high-concentration oxygen from, for example, air through adsorption removal of nitrogen from the air and supplying the high-concentration oxygen to, for example, a patient. The present invention further relates to a controller and a recording medium for the oxygen enriching apparatus.

2. Description of the Related Art:

Conventionally, an oxygen enriching apparatus for medical use capable of producing an oxygen-enriched gas from, for example, air through adsorption removal of nitrogen from the air and supplying high-concentration oxygen to a patient has been used in, for example, home care oxygen therapy.

Since a patient who uses such an oxygen enriching apparatus is weak in lung function as compared with healthy persons, the patient must use the oxygen enriching apparatus all day long. Therefore, an oxygen enriching apparatus which can be used conveniently for daily living has been in demand.

When the condition of the patient is good, the flow rate of the oxygen-enriched gas (hereinafter also referred to as "oxygen flow rate") is typically set

to 2 liters/min or less (hereinafter “min” may be omitted), and this flow rate is sufficient. However, when the condition of the patient becomes worse, an oxygen flow rate of greater than 2 liters/min is required, and in order to provide a margin for safety, an oxygen flow rate of about 5 to 7 liters/min is required.

3. Problems Solved by the Invention:

When the capacity of the oxygen enriching apparatus is increased, the oxygen-enriched gas can be supplied at a higher flow rate. However, in such a case, the size of the oxygen enriching apparatus increases, raising the following problems (1) to (3).

(1) Since the volume and weight of the oxygen enriching apparatus increase, a large burden is imposed on a caregiver when he or she transports or moves the oxygen enriching apparatus.

In an example case in which a caregiver or a sales representative transports the oxygen enriching apparatus to the patient’s house and installs it there, the caregiver or sales representative cannot perform the installation work by himself because of the large size of the apparatus, and the caregiver or sales representative must bear a considerably large burden.

(2) Due to increased consumption of electrical power, there is a resultant increase in cost.

For example, the electrical-power consumption of an oxygen enriching apparatus having a capacity of 5 to 7 liters/min (5 to 7 liter model) (450W) is about two times that of a conventional 2 liter or 3 liter model.

(3) Increased noise hinders good sleep of the patient. When a measure for the noise is employed, the volume and weight of the oxygen enriching apparatus increase further.

For example, if a soundproofing material is disposed as a measure against noise during operation, the volume and weight of the oxygen enriching apparatus increase further, and the increased weight (45 Kg) is about two times that of the conventional 2 liter or 3 liter model. However, in spite of provision of the soundproofing material, the noise level is still high, thus failing to guarantee that the patient will sleep well.

That is, conventional oxygen enriching apparatus for medical use and ordinary oxygen enriching apparatus are based on the same design concept. Therefore, when oxygen is to be supplied at a flow rate of 5 liters/min, the capacity of a compressor and the amount of an adsorbing material for adsorbing nitrogen must be increased, and an electromagnetic valve of a larger diameter suitable for the increased flow rate must be used as an electromagnetic valve for controlling the feeding of compressed air from the compressor to the adsorbing material. Consequently, the sizes of components naturally increase, and the above-described problems (1) to (3) arise.

Apart from the above-described technique regarding oxygen enriching apparatus, a technique has been developed in which a patient carries an oxygen cylinder with him or her during travel or at the time of visiting a hospital.

In this technique, a breath synchronizer for supplying oxygen synchronously with breathing is used so as to reduce consumption of oxygen supplied from the cylinder, to thereby extend the service life of the oxygen cylinder.

5 The breath synchronizer utilizes the rule of thumb that in the case of a human the ratio between the inhalation period and the exhalation period is 1:2. Upon detection of inhalation by means of a sensor, the breath synchronizer supplies high-concentration oxygen from the oxygen cylinder over a short period of time (in the manner of a pulse).

10 The technique can reduce the consumption of oxygen stored in the oxygen cylinder and the consumption of drive batteries, because high-pressure oxygen is supplied from the oxygen cylinder only for a short period of time upon start of inhalation. However, the technique involves another problem in that the patient feels that something is wrong, because the breath synchronizer
15 creates a breathing condition that differs from ordinary breathing condition.

In recent years, a technique for applying the breath synchronization technique used with an oxygen cylinder to an oxygen enriching apparatus has been proposed (see, for example, Japanese Patent Application Laid-Open (*kokai*) No. 8-187289). However, effective ways for solving the above-
20 described problems caused by the increased apparatus size have hardly been studied.

SUMMARY OF THE INVENTION

Next, various embodiments of the present invention are described as follows.

(1) In a first embodiment, the invention provides an oxygen enriching apparatus which enriches oxygen contained in air to thereby obtain oxygen-enriched gas, and which supplies the oxygen-enriched gas to a user having a breathing cycle including an inhalation period and an exhalation period synchronously with inhalation of the user by means of a breath synchronization function, which comprises an oxygen outlet for supplying the oxygen-enriched gas to an inhalator of the user, and a breath detection port connected to the inhalator for detecting the user's state of breathing.

The oxygen enriching apparatus of the present invention has an oxygen outlet and a breath detection port.

Of these, the oxygen outlet is an opening portion for supplying oxygen-enriched gas to a user. When the breath synchronization function is not used, the oxygen-enriched gas is continuously supplied to the user at a constant flow rate. When the breath synchronization function is used, the oxygen-enriched gas is supplied to the user while the supply flow rate is changed in accordance with breathing cycles.

Meanwhile, the breath detection port is an opening portion to which an inhalator (e.g., a tube of a nasal cannula) is connected so as to detect the user's state of breathing. The oxygen-enriched gas is not supplied to the user from the breath detection port. Accordingly, when a pressure sensor, for example, is disposed at the breath detection port, pressure changes that propagate to the

breath detection port via the inhalator can be detected in order to grasp the user's state of breathing (timings of inhalation and exhalation).

In particular, when the breath-synchronized operation is performed, oxygen-enriched gas is continuously supplied to the user throughout each breathing cycle, including inhalation and exhalation periods (while the supply flow rate is changed). Therefore, if a pressure sensor is disposed at the oxygen outlet, the state of breathing (pressure changes due to breathing) is difficult to detect.

By contrast, in the present invention, a breath detection port (to which no oxygen-enriched gas is supplied) is provided separately from the oxygen outlet. Therefore, when a pressure sensor, for example, is disposed at the breath detection port, the state of breathing can be accurately determined. Thus, control (control for changing flow rate) for the breath-synchronized operation can be performed accurately in accordance with the thus determined breathing state.

The above-described "breath-synchronized operation" refers to an operation for changing the supply flow rate of oxygen-enriched gas in order to substantially match the user's spontaneous inhaling and exhaling action within each breathing cycle.

Example configurations for enriching oxygen include a configuration which uses, for example, an adsorbent for selectively adsorbing and removing nitrogen contained in air, and a configuration which uses a membrane that is permeable to oxygen.

Notably, the present invention can be suitably applied to the case in which oxygen is supplied to a user by use of a so-called open system which uses a nasal cannula, for example.

(2) A second embodiment of the invention comprises means for
5 supplying the oxygen-enriched gas at a first flow rate during the inhalation period of each breathing cycle and at a second flow rate during the exhalation period of each breathing cycle when breath-synchronized operation is performed, wherein the first flow rate is greater than a continuous base flow rate representing a flow rate at which the oxygen enriching apparatus can
10 supply the oxygen-enriched gas continuously, and the second flow rate is less than the continuous base flow rate.

The second embodiment exemplifies control for the case in which the breath-synchronized operation is performed.

In the present embodiment, a continuous base flow rate represents a
15 continuously-supplyable flow rate (that is, a continuous supply capacity which represents the maximum flow rate at which the oxygen enriching apparatus can supply oxygen-enriched gas continuously). For example, in the case of a 3 liter model, the continuous base flow rate is set to 3 liters/min. When the breath-synchronized operation is performed, during the inhalation period of
20 each breathing cycle oxygen-enriched gas is supplied to the user at a first flow rate (e.g., 5 liters/min) greater than the continuous base flow rate, and during the exhalation period of each breathing cycle oxygen-enriched gas is supplied

at a second flow rate (e.g., 2 liters/min) less than the continuous base flow rate.

That is, in the present embodiment, although the oxygen-enriched gas is continuously supplied to the user in both the inhalation and exhalation periods of each breathing cycle, the oxygen-enriched gas is supplied at a high flow rate in each inhalation period and at a low flow rate in each exhalation period, which flow rates can be set freely.

As described above, in the present embodiment, the oxygen-enriched gas can be supplied at a high flow rate during each inhalation period, and can be supplied at a flow rate of some level during each exhalation period. The user can breath without feeling any unnatural sensation, as in the case of ordinary breathing. In addition, safety is considerably high.

In the present embodiment, during each exhalation period, the oxygen enriching apparatus is merely required to supply oxygen-enriched gas at a low flow rate less than the continuous base flow rate. Therefore, the oxygen enriching apparatus can have a small body (lightweight and small volume), as in the case of, for example, a 3 liter model. In other words, in spite of the small body, the oxygen enriching apparatus can supply oxygen at a high flow rate when necessary (during each inhalation period when the breath-synchronized operation is performed).

Therefore, the present embodiment achieves the following effects, among others. (1) Since the volume and weight of the oxygen enriching apparatus do not increase, the burden imposed on a sales representative or a

caregiver can be decreased. (2) Since electrical-power consumption does not increase, electricity cost is low. (3) Since the level of noise is low, the noise does not hinder good sleep of the patient. In addition, even when a measure against the noise is employed, the volume and weight of the oxygen enriching apparatus do not increase very much.

Notably, each of the above-described continuous base flow rate, first flow rate, and second flow rate is a unit flow rate which represents an amount of oxygen-enriched gas supplied over a certain time and can be represented by a volume of a gas (at 1 atm) supplied over, for example, 1 min.

(3) A third embodiment of the invention comprises means for supplying the oxygen-enriched gas at a third flow rate equal to or less than the continuous base flow rate when the breath-synchronized operation is not performed, at which third flow rate the oxygen enriching apparatus can supply the oxygen-enriched gas continuously.

The third embodiment exemplifies the case in which the breath-synchronized operation is not performed.

In the present embodiment, when the breath-synchronized operation is not performed (i.e., in the case of continuous supply), the oxygen enriching apparatus is merely required to supply oxygen-enriched gas at a low flow rate less than the continuous base flow rate. Therefore, the oxygen enriching apparatus can have a small body (lightweight and small volume) of, for example, a 3 liter model. In other words, in spite of the small body, the oxygen enriching apparatus can supply oxygen at a high flow rate when

For example, the timing for starting or ending the supply of the oxygen-enriched gas in each breathing cycle can be determined on the basis of the signal output from the sensor.

(6) A sixth embodiment of the invention comprises means for
5 detecting the state of inhalation or exhalation one time or a plurality of number
of times based on the signal output from the sensor, and for determining the
timing for starting or ending subsequent supply of the oxygen-enriched gas
based on the thus-detected state of inhalation or exhalation. In the present
embodiment, the timing for starting or ending the supply of the oxygen-
10 enriched gas is determined based on stored past data.

For example, since the length of a single breathing cycle can be found
by measuring of a time between the start of a first inhalation and the start of a
second inhalation, in the next breathing cycle, a predetermined period (e.g., a
period of 1/3 the breathing cycle) starting from the start of inhalation is set as
15 an inhalation period, and oxygen-enriched gas is supplied at a high flow rate
over the inhalation period. Preferably, this operation is repeated continuously.

Since the above operation enables accurate supply of oxygen-enriched
gas in a proper amount over the user's inhalation and exhalation periods, the
user does not feel any unnatural sensation.

20 Notably, a predetermined, fixed value may be used as the length of the
inhalation period until the length of the inhalation period is calculated from the
data.

Moreover, since accuracy in calculating the length of the inhalation period can be increased by using an average of a plurality of data sets, the length of the inhalation period may be updated continuously by use of, for example, an average of a plurality of past data sets.

5 (7) A seventh embodiment of the invention comprises a main passage extending to the oxygen outlet and adapted to supply the oxygen-enriched gas thereto, said main passage comprising a control member (e.g., an electromagnetic valve) for adjusting the opening of the main passage, and a bypass flow passage for bypassing the control member.

10 Accordingly, even when the main supply passage is closed, the oxygen-enriched gas can be supplied at a predetermined flow rate (e.g., at the second flow rate) at all times.

For example, even when the breath-synchronized operation is performed and thus the flow rate of the oxygen-enriched gas passing through the main supply passage is changed by opening and closing of the main supply passage, a predetermined flow rate can be secured at all times, so that the user feels reduced unnatural sensation.

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(8) An eighth embodiment of the invention comprises a flow-rate adjuster provided in the bypass flow passage in order to adjust the flow rate of the oxygen-enriched gas flowing through the bypass flow passage.

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Therefore, in the present embodiment, the bypass flow rate (e.g., the second flow rate) can be adjusted by using the flow-rate adjuster.

(9) In a ninth embodiment, the present invention provides an oxygen enriching apparatus which enriches oxygen contained in air to thereby obtain oxygen-enriched gas and which supplies the oxygen-enriched gas to a user having a breathing cycle including an inhalation period and an exhalation period synchronously with inhalation of the user by means of a breath synchronization function, which comprises means for supplying the oxygen-enriched gas at a first flow rate during the inhalation period of each breathing cycle and at a second flow rate during the exhalation period of each breathing cycle when breath-synchronized operation is performed, wherein the first flow rate is greater than a continuous base flow rate representing a flow rate at which the oxygen enriching apparatus can supply the oxygen-enriched gas continuously, and the second flow rate is less than the continuous base flow rate.

In the present embodiment, as in the case of the second embodiment, the continuous base flow rate indicates a continuously-supplyable flow rate (that is, a continuous supply capacity which represents the maximum flow rate at which the oxygen enriching apparatus can supply the oxygen-enriched gas continuously). For example, in the case of a 3 liter model, the continuous base flow rate is set to 3 liters/min. When the breath-synchronized operation is performed, during the inhalation period of each breathing cycle oxygen-enriched gas is supplied to the user at a first flow rate (e.g., 5 liters/min) greater than the continuous base flow rate, and during the exhalation period of

each breathing cycle the oxygen-enriched gas is supplied at a second flow rate (e.g., 2 liters/min) less than the continuous base flow rate.

That is, in the present embodiment, although the oxygen-enriched gas is continuously supplied to the user during both the inhalation and exhalation periods of each breathing cycle, the oxygen-enriched gas is supplied at a high flow rate during each inhalation period and at a low flow rate during each exhalation period.

As described above, in the present embodiment, the oxygen-enriched gas can be supplied at a high flow rate during each inhalation period, and can be supplied at a flow rate of some level during each exhalation period. Therefore, the breath-synchronized operation performed by use of the sensor does not suffer any delay, and the user can breath without feeling any unnatural sensation, as in the case of ordinary breathing. In addition, since the oxygen-enriched gas of some amount can be secured even in the event of failure to attain breath synchronization, the level of safety is high.

In the present embodiment, during each exhalation period, the oxygen enriching apparatus is merely required to supply the oxygen-enriched gas at a low flow rate less than the continuous base flow rate. Therefore, the oxygen enriching apparatus can have a small body (lightweight and small volume) of, for example, a 3 liter model. In other words, in spite of the small body, the oxygen enriching apparatus can supply oxygen at a high flow rate when necessary (during each inhalation period when the breath-synchronized operation is performed).

Although the length of the inhalation period is generally about 1/3 of the length of the breathing cycle, the length varies slightly depending on the user and his condition. In view of this, in the present invention, oxygen-enriched gas is supplied at a high flow rate during the inhalation period, which
5 has a length 25 to 40% that of the user's breathing cycle.

(12) In a twelfth embodiment of the invention, the continuous base flow rate is 4 liters/min or less.

That is, as described above, a small apparatus whose continuous base flow rate is 4 liter or less is excellent in terms of easiness of transport,
10 electricity cost, and noise. In the present invention, even when a small apparatus whose continuous base flow rate is 4 liters/min or less is used, oxygen-enriched gas can be supplied at a flow rate (e.g., 5 to 7 liters/min) greater than the continuous base flow rate through performance of breath-synchronized operation. Therefore, the above-described advantages of a small
15 apparatus can be obtained to the maximum extent.

(13) A thirteenth embodiment of the invention comprises a tank provided in the oxygen-enriched-gas supply passage on the downstream side of an oxygen enriching section (e.g., a section in which oxygen is adsorbed for enrichment), for accumulating oxygen-enriched gas supplied during the
20 exhalation period of the breathing timing.

Accordingly, in the present embodiment, a sufficient amount of oxygen-enriched gas can be accumulated in the tank during each exhalation period.

(14) A fourteenth embodiment of the invention comprises a plurality of tanks provided in series in the oxygen-enriched-gas supply passage, on the downstream side of the oxygen enriching section, for stably supplying the oxygen-enriched gas.

5 When a small apparatus (e.g., having a continuous base flow rate of 3 liter/min) supplies oxygen-enriched gas during each inhalation period at a high flow rate through performance of breath-synchronized operation, pressure fluctuations stemming from changes in supply flow rate of the oxygen-enriched gas may influence the oxygen enriching section. In the present
10 embodiment, since a plurality of serially connected tanks are provided, if such pressure fluctuations are generated, the tanks absorb the pressure fluctuations.

Accordingly, since pressure fluctuations do not influence the oxygen enriching section, stable oxygen enriching (e.g., adsorption of nitrogen) can be performed, and thus oxygen-enriched gas can be supplied stably.

15 (15) In a fifteenth embodiment of the invention, each of two tanks connected in series has a capacity of at least 500 ml (e.g., about 750 ml).

This embodiment exemplifies the volume of tanks provided in a small apparatus (e.g., 3 liter model) whose continuous base flow rate of oxygen-enriched gas is 3 liters/min. When the tanks have the above-described
20 capacity, the tanks can accumulate a sufficient amount of oxygen-enriched gas during each exhalation period.

That is, in the case of a 3 liter model, when two serially connected tanks each having a capacity of 500 ml or more are provided, the above-described influence of pressure fluctuations can be effectively prevented.

(16) A sixteenth embodiment of the invention comprises a check valve for preventing reverse flow toward the oxygen enriching section disposed between the plurality of tanks.

Accordingly, even when the above-described pressure fluctuations are generated, their propagation can be prevented by the check valve, so that adverse effect of the pressure fluctuations can be prevented.

(17) A seventeenth embodiment of the invention comprises a switch (manual switch) for setting a flow rate of oxygen-enriched gas. When the flow rate is set by use of the switch to the third flow rate equal to or less than the continuous base flow rate, the oxygen enriching apparatus supplies the oxygen-enriched gas continuously. When the flow rate is set by use of the switch to the first flow rate greater than the continuous base flow rate, the oxygen enriching apparatus supplies the oxygen-enriched gas by means of the breath-synchronized operation.

In an example case in which the continuous base flow rate is 3 liters/min, the third flow rate (which is a flow rate for continuous supply) can be set to a desired value by operating the manual switch if the desired value is not greater than 3 liters/min.

Further, when the flow rate is set by use of the manual switch to a value greater than 3 liters/min, the control mode is automatically switched to

the mode for performing breath-synchronized operation. In an example case in which the flow rate is set to 5 liters/min, the breath-synchronized operation is performed such that oxygen-enriched gas is supplied at 5 liters/min during each inhalation period.

5 (18) In an eighteenth embodiment, the invention is directed to a controller for controlling operation of the oxygen enriching apparatus. The controller may be integrated with (built in) the oxygen enriching apparatus or may be separated from the oxygen enriching apparatus.

10 (19) In a nineteenth embodiment, the invention is directed to a recording medium having recorded thereon means (e.g., a program) for executing the function of the controller.

When the function of the controller is realized by use of a computer system, the function can be provided in the form of a program which is executed in the computer system. Such a program can be recorded on a
15 computer-readable medium, such as a floppy disk, a magnetic optical disk, CD-ROM, or a hard disk drive, and when necessary can be loaded on the computer system and started so as to use the program. Alternatively, the program may be stored in ROM or backup RAM serving as a computer-readable recording medium, which is then incorporated into the computer
20 system.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an explanatory view showing the basic structure of an oxygen enriching apparatus of an embodiment of the invention.

Fig. 2 is an explanatory view showing a cannula with tubes connected thereto.

Fig. 3 is a block diagram showing the electrical configuration of a controller of the oxygen enriching apparatus of the embodiment.

5 Fig. 4 is an explanatory view showing breathing cycles.

Fig. 5 is a flowchart showing the basic control processing performed by the controller of the embodiment.

Fig. 6 is a flowchart showing the electromagnetic-valve control processing performed by the controller of the embodiment.

10 Fig. 7 is an explanatory view showing the structure of an oxygen enriching apparatus of another embodiment of the invention.

Description of Reference Numerals:

1: oxygen enriching apparatus

19a, 19b, 19: adsorption tubes

15 17a, 17b, 17: directional control valves

29a: main flow passage

33, 37: product tanks

31a, 31b, 35, 39: check valves

45, 61: flow-rate setting units

20 44, 65: electromagnetic valves

50: bypass flow passage

53, 67: pressure sensors

54, 79: breath detection ports

59, 69: controllers

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

An example mode (embodiment) of the oxygen enriching apparatus, controller, and recording medium of the present invention will be described with reference to the drawings. However, the present invention should not be construed as being limited thereto.

The embodiment will be described, taking an oxygen enriching apparatus for medical use (hereinafter referred to as an "oxygen enriching apparatus") which has a built-in controller as an example.

10 The oxygen enriching apparatus of the present embodiment enriches oxygen contained in air through adsorption removal of nitrogen from the air and continuously supplies an oxygen-enriched gas to a patient, which is a user, at a third flow rate (e.g., 3 liters/min), which is equal to or less than a continuous base flow rate. Further, in case of need, the oxygen enriching apparatus switches its operation to breath-synchronized operation in order to supply the oxygen-enriched gas over each inhalation period of the patient at a first flow rate (e.g., 5 liters/min), which is greater than the continuous base flow rate. In addition, over each exhalation period, the oxygen enriching apparatus supplies the oxygen-enriched gas at a second flow rate (e.g., 2
15 liters/min), which is less than the continuous base flow rate.

a) First, the basic structure of the oxygen enriching apparatus will be described.

As shown in Fig. 1, the oxygen enriching apparatus 1 of the present embodiment is accommodated in a main-body case 3. In an air introduction passage 5 are provided, in the sequence given from the upstream end, an air intake port 7, an intake air filter 9 for removing dust and dirt, a sound absorber 11 for lowering sound generated upon intake of air, a compressor 13 for compressing air, a heat exchanger 15 for cooling compressed air, a pair of directional control valves 17a and 17b (collectively denoted by 17) for switching between three flow passages, and a pair of adsorption tubes 19a and 19b (collectively denoted by 19).

10 A sirocco fan 21 for cooling the compressor 13 and the heat exchanger 15 is provided in the vicinity thereof.

A sound absorber 25 similar to the above and a silencer 27 for eliminating intermittent exhaust noise are provided in a discharge passage 23, which extends from the directional control valves 17 and is adapted to
15 discharge nitrogen from the pair of adsorption tubes 19.

Moreover, in a supply passage 29, which extends from the pair of adsorption tubes 19 and is adapted to supply oxygen-enriched gas, are provided, in the sequence given from the upstream side, a pair of check valves 31a and 31b for preventing reverse flow toward the adsorption tubes 19, a first
20 product tank 33 for storing oxygen-enriched gas, a check valve 35 for preventing reverse flow toward the first product tank 33, a second product tank 37 for storing oxygen-enriched gas, a check valve 39 for preventing reverse flow toward the second product tank 37, a regulator 41 for lowering

the pressure of oxygen, a bacteria filter 43 for preventing passage of bacteria or the like, a flow-rate setting unit 45 for setting a supply flow rate of oxygen-enriched gas, an electromagnetic valve 47 for opening/closing a main flow passage 29a, and an oxygen outlet 49 for supplying oxygen-enriched gas.

5 Further, a bypass flow passage 50 for bypassing the electromagnetic valve 47 is provided for the main flow passage 29a connected to the supply passage 29. A flow-rate adjuster 52 for adjusting the flow rate (second flow rate) of oxygen-enriched gas flowing through the bypass flow passage 50 is provided in the bypass flow passage 50.

10 Moreover, in the present embodiment, separately from the oxygen outlet 49, a breath detection port 54 (to which no oxygen-enriched gas is supplied) is provided. A pressure sensor 53 for detecting pressure during inhalation is disposed at the breath detection port 54. 87

15 An oxygen sensor 51 for detecting oxygen concentration is disposed between the check valve 39 and the regulator 41.

As shown by a broken line in Fig. 1, in the oxygen enriching apparatus 1 of the present embodiment, not only the compressor 13 but also the intake air filter 9, the sound absorbers 11 and 25, the heat exchanger 15, the directional control valves 17, the silencer 27, and the sirocco fan 21 are
20 accommodated within a metal case 57 lined with vibration-absorbing rubber and a sound-absorbing material to thereby reduce noise during operation.

The oxygen enriching apparatus 1 having the above-described structure is a small apparatus whose continuous base flow rate is 3 liters/min. The

apparatus has a weight of 32 kg, a power consumption of 210 W, and operating noise of 30 dB or less.

b) Next, the above-described respective components will be described in more detail.

5 Each of the above-described directional control valves 17 is a three-port directional control valve which operates under control of a controller 59. Through changeover operation, the directional control valves 17 selectively create a state in which the communication between the heat exchanger 15 and the adsorption tubes 19 is established and the communication between the
10 adsorption tubes 19 and the discharge passage 23 is broken, and a state in which the communication between the heat exchanger 15 and the adsorption tubes 19 is broken and the communication between the adsorption tubes 19 and the discharge passage 23 is established.

15 The pair of adsorption tubes 19 are filled with a zeolite-containing adsorbent. This adsorbent has characteristics such that when pressurized (to, e.g., 2 atm (gauge pressure)), the adsorbent preferentially adsorbs nitrogen contained in air; and when the pressure is lowered (to, e.g., atmospheric pressure), the adsorbent releases the adsorbed nitrogen in order to self-regenerate.

20 The product tanks 33 and 37 each have a capacity of 750 ml and form a reservoir for oxygen-enriched gas.

That is, the product tanks 33 and 37 suppress variations in supply amount of oxygen-enriched gas to thereby enable continuous supply. Further,

and 37, to 0.35 atm (gauge pressure), at which a patient inhales the gas with ease.

The flow-rate setting unit 45 enables manual flow-rate setting.

That is, by adjusting an orifice, the continuous base flow rate (third
5 flow rate) can be set within a range up to the continuous base flow rate (3
liters/min). When a flow rate greater than the continuous base flow rate is set
by adjusting the orifice, the control is switched to the breath-synchronized
control in order to discharge oxygen-enriched gas accumulated in a preceding
exhalation period to thereby enable supply of oxygen-enriched gas at a set
10 high flow rate (first flow rate).

As shown in Fig. 2, a first tube 58 extending from a cannula (nasal
cannula) 56 used by a patient is connected to the oxygen outlet 49.
Accordingly, oxygen-enriched gas is supplied from the oxygen outlet 49 at a
predetermined flow rate set by use of the flow-rate setting unit 45 and under
15 pressure reduced to 0.35 atm by means of the regulator 41.

As shown in Fig. 2, a second tube 60 branching from the cannula 56 is
connected to the breath detection port 54. The pressure sensor 53 disposed at
the breath detection port 54 can detect, from a pressure fluctuation, a time at
which each inhalation period starts.

20 A pair of opening portions 57 and 59 (inserted into the nose) of the
cannula 56 are each divided into semicircular first and second opening
portions 57a, 59a and 57b, 59b. The first opening portions 57a and 59a
communicate with the oxygen outlet 49 via the first tube 58. The second

opening portions 57b and 59b communicate with the breath detection port 54 via the second tube 60.

The flow-rate adjuster 52 fixedly sets a bypass flow rate to an arbitrary value by use of a needle valve. In the present embodiment, the bypass flow rate is set to 2 liters/min. Accordingly, even when the electromagnetic valve 47 shuts off the main flow passage 29a, oxygen-enriched gas can be supplied via the bypass flow passage 50.

c) Next, the electrical configuration of the controller 59 and other components for controlling the oxygen enriching apparatus 1 will be described.

In the present embodiment, as shown in Fig. 3, the controller 59 includes a microcomputer as a main element and is disposed inside the oxygen enriching apparatus 1. The controller 59 includes a CPU 59a, ROM 59b, RAM 59c, an input/output section 59d, a bus line 59e, etc., which are well known.

The flow-rate setting unit 45, the oxygen sensor 51, and the pressure sensor 53 are connected to the input/output section 59d of the controller 59. Further, the directional control valves 17 and the electromagnetic valve 47 are connected to the input/output section 59d as actuators.

Thus, the controller 59 performs a predetermined calculation on the basis of signals obtained from the flow-rate setting unit 45, the oxygen sensor 51, and the pressure sensor 53, and controls the operations of the directional control valves 17 and the electromagnetic valve 47.

d) Next, major functions of the oxygen enriching apparatus 1 according to the present embodiment will be described.

(1) Oxygen enriching function

In the present embodiment, by means of the directional control valves 5 17, the connections among the heat exchanger 15, the adsorption tubes 19, and the discharge passage 23 are switched in order to change the pressure applied to the adsorption tubes 19 to thereby enrich oxygen contained in air.

For example, a state in which one adsorption tube 19a communicates with the heat exchanger 15 via one directional control valve 17a is established, 10 and compressed air is fed to the adsorption tube 19a by the compressor 13 to thereby apply pressure to the adsorption tube 19a. At this time, the communication between the adsorption tube 19a and the discharge passage 23 is broken by means of the directional control valve 17a.

Upon application of pressure, inside the adsorption tube 19a, nitrogen 15 contained in air is adsorbed by the adsorbent, so that oxygen is enriched, and oxygen-enriched gas is supplied to the supply passage 29.

When the pressure of the adsorption tube 19a reaches about 2 kg/cm^2 (about 2 atm), which is the highest pressure for nitrogen adsorption, the other directional control valve 17b is operated in order to increase the internal 20 pressure of the adsorption tube 19b in a similar manner. At this time, the communication between the adsorption tube 19a and the discharge passage 23 is established by means of the directional control valve 17a.

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Through the above-described changeover, the internal pressure of the adsorption tube 19a communicating with the discharge passage 23 decreases to atmospheric pressure. Therefore, nitrogen is released from the adsorbent, and the adsorbent is regenerated. At the same time, the released nitrogen is discharged to the outside via the discharge passage 23 as the internal pressure of the adsorption tube 19 decreases.

When pressure is repeatedly applied to the two adsorption tubes 19 alternately through control of the two directional control valves 17 in the above-described manner, enriched oxygen of 90% or greater (about 90 to 95%) can be continuously supplied.

That is, these adsorption tubes 19 make it possible to extract oxygen solely upon application of pressure, and to supply oxygen of high concentration to the oxygen outlet 49 via the first and second product tanks 33 and 37 located downstream of the adsorption tubes 19.

The directional control valves 17 are switched at a timing at which the internal pressure of the adsorption tubes 19 reaches 2 atm. In the present embodiment, instead of using a pressure sensor for determining the timing, a timer is used in order to perform the switching.

That is, since the performance of the compressor 13 does not change very much, the internal pressure of the adsorption tubes 19 reaches 2 atm after passage of a predetermined period of time. Accordingly, every time the predetermined period of time has elapsed, the directional control valves 17 are

switched to thereby change the adsorption tube 19 to be pressurized and the adsorption tube 19 from which nitrogen is to be discharged.

(2) Breath synchronization function

Here, the case is considered in which, by use of the flow-rate setting unit 45, which is a manual switch, the flow rate of oxygen-enriched gas is set to, for example, 5 liters/min, which is greater than the continuous base flow rate, and thus, breath-synchronized control is started.

When the flow rate of oxygen-enriched gas is manually set to 5 liters/min by use of the flow-rate setting unit 45, a state which enables supply of oxygen-enriched gas at 5 liters/min is created through combined use of internal orifices.

At this time, the bypass flow rate is adjusted to 2 liters/min by means of the flow-rate adjuster 52. Therefore, oxygen-enriched gas can be supplied at least at 2 liters/min over the entire period of each breathing cycle; more specifically, over the exhalation period.

The highly-sensitive pressure sensor (e.g., a semiconductor pressure sensor) 53 connected to the vicinity of the breath detection port 54 detects a slight negative pressure (0.4 mmH₂O) which is produced when the patient inhales oxygen via the cannula 56. In response to detection of the negative pressure, the controller 59 opens and closes the electromagnetic valve 47 such that oxygen-enriched gas is supplied at a high flow rate (5 liters/min) over the inhalation period of each breathing cycle of the patient, as shown in Fig. 4.

In other words, since the capacity of the oxygen enriching apparatus 1 is 3 liters/min (3 liter model), when the patient needs a flow rate greater than 3 liters/min, electrical changeover is effected in order to provide breath-synchronized operation. Thus, it becomes possible to supply oxygen-enriched gas at a high flow rate of 5 liters/min (total flow rate) by utilizing oxygen-enriched gas (2 liters) stored in the product tanks 33 and 37.

Moreover, in the present embodiment, the controller 59 detects inhalation by use of the pressure sensor 53; calculates an averaged breathing cycle time from an average value of the past two to five breathing cycle times; regards one-third of the averaged breathing cycle time as an inhalation period; and opens the electromagnetic valve 47 over the inhalation period to thereby supply oxygen-enriched gas to the patient.

e) Next, a main portion of control processing performed in the controller 59 of the present embodiment will be described with reference to a flowchart shown in Fig. 5.

(1) Basic control for flow-rate setting

First, the basic control for setting a supply flow rate by use of the flow-rate setting unit 45 will be described.

In step 100 of Fig. 5, the controller 59 makes a judgment as to whether the flow rate set by use of the flow-rate setting unit 45 is equal to or less than the continuous base flow rate (3 liters/min). When the result of judgment is "Yes", the controller 59 proceeds to step 110. When the result of judgment is "No", the controller 59 proceeds to step 120.

described below, the controller 59 opens and closes the electromagnetic valve 47 in order to supply oxygen-enriched gas at a high flow rate during the inhalation period of each breathing cycle and at a low flow rate during the exhalation period of each breathing cycle. Subsequently, the controller 59 suspends the present processing.

(2) Control of the electromagnetic valve 47

Next, control of the electromagnetic valve 47 performed in the above-described step 140 will be described.

In step 200 of Fig. 6, on the basis of the result of detection performed
by the pressure sensor 53, the controller 59 judges whether inhalation has
started. When the result of judgment is "Yes," the controller 59 proceeds to
step 210. When the result of judgment is "No," the controller 59 suspends the
present processing. That is, when the pressure decreases to a predetermined
reference value (e.g., -0.4 mmH₂O) or less, the controller 59 judges that
inhalation has started.

In step 210, the controller 59 opens the electromagnetic valve 47, because the patient has started inhalation.

In subsequent step 220, the controller 59 stores in, for example, RAM 59c the timing (time) at which start of the inhalation was detected.

20 In subsequent step 230, the controller 59 judges whether the number of breathing cycles having been performed after the control was switched to the breath-synchronized control is equal to or less than a predetermined number (e.g., 3). When the result of judgment is “Yes,” the controller 59 proceeds to

step 240. When the result of judgment is "No," the controller 59 proceeds to step 270.

In step 240, since the breathing cycle has been performed twice or less, the controller 59 uses a fixed value representing a preset timing (e.g., 4
5 seconds from the start of inhalation) as a timing for closing the electromagnetic valve 47 (i.e., a timing of end of a corresponding inhalation period).

The reason why 4 seconds is used as the fixed value is as follows. Although in the case of a human the number of times of breathing (per min) is
10 typically 20 times on average, the number of times of breathing is expected to vary within a range of 5 to 50 times. In the slowest case (5 times), the length of each breathing cycle is 12 seconds, and the length of each inhalation period is one-third thereof; i.e., 4 seconds. The length of this longest inhalation period is used as the fixed value.

15 In subsequent step 250, the controller 59 waits until the inhalation period ends.

In step 260, since the inhalation period has ended, the controller 59 closes the electromagnetic valve 47 to thereby stop supply of oxygen-enriched gas via the main flow passage 29a. Subsequently, the controller 59 suspends
20 the present processing.

Notably, even when the main flow passage 29a is closed by the electromagnetic valve 47, supply of oxygen-enriched gas via the bypass flow passage 50 at 2 liters/min is continued.

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Meanwhile, when the controller 59 proceeds to step 270 as a result of the negative judgment in the above-mentioned step 230, this means that start of inhalation has been detected three times or more (i.e., two breathing cycles have been detected). Therefore, the controller 59 obtains an average length of the breathing cycles from data regarding the timing of inhalation in the two breathing cycles, and divides the average length by three to thereby obtain the length of each inhalation period. The average length is regularly updated to the latest value through calculation which is performed after addition of data of the latest breathing cycle.

10 In subsequent step 280, the controller 59 sets the inhalation-period length calculated in step 270 as a timing for closing the electromagnetic valve 47 (i.e., the timing of end of the corresponding inhalation period). Thus, the length of time between the start and end of the corresponding inhalation period is set.

15 Subsequently, similar to the above-described case, the controller 59 proceeds to step 250 and waits until the inhalation period ends; and in subsequent step 260 closes the electromagnetic valve 47 at the timing of end of the inhalation period to thereby stop supply of oxygen-enriched gas via the main flow passage 29a. Subsequently, the controller 59 suspends the present processing.

f) As described above, the oxygen enriching apparatus 1 according to the present embodiment is a small apparatus capable of continuously supplying oxygen-enriched gas at 3 liters/min. However, when a

synchronized operation in which oxygen-enriched gas is supplied continuously while its flow rate is varied, the timing at which the patient starts inhalation of the breathing cycle can be detected accurately.

Accordingly, the supply flow rate of oxygen-enriched gas can be
5 changed at proper timings, on the basis of the detected timing of start of inhalation.

In addition, in the present embodiment, data regarding breathing cycles of the patient are accumulated, and the length of each inhalation period is obtained from the data. Therefore, an accurate value for the length of each
10 inhalation period can be obtained.

Moreover, in the present embodiment, the product tanks (750 ml) 33 and 37 are disposed in series, and the check valve 35 is disposed between them. Therefore, even when the supply flow rate of oxygen-enriched gas is changed by means of the breath-synchronized control and thus a pressure
15 fluctuation occurs, the pressure fluctuation can be prevented from propagating to the adsorption tubes 19.

The present invention is not limited to the above-described embodiment, and may be practiced in various forms without departing from the scope of the present invention. For example:

20 (1) In the above-described embodiment, an oxygen enriching apparatus and a controller therefore have been described. However, the present invention is not limited thereto, and encompasses a recording medium which stores means for executing the above-described processing.

Examples of such a recording medium include a microchip, a floppy disk, a hard disk drive, an optical disk, and electronic control devices (ROM, RAM, EPROM, EEPROM, etc.) which are incorporated in a microcomputer. In other words, no limitation is imposed on the recording medium, insofar as
 5 the selected recording medium stores means, such as a program, which can execute the above-described processing of the oxygen enriching apparatus and the controller.

(2) The above-described embodiment exemplifies the case in which the controller is built in the oxygen enriching apparatus. However, the
 10 controller may be separated from the oxygen enriching apparatus.

For example, as shown in Fig. 7, a controller unit 71 including a flow-rate setting unit 61, a flow-rate adjuster 63, an electromagnetic valve 65, a pressure sensor 67, a controller 69, etc. may be separated from a main body case 3, which accommodates the remaining large components such as the
 15 compressor 13 and the adsorption tubes 19.

In such a case, a tube 75 serving as a passage for supplying oxygen-enriched gas is extended from the oxygen outlet 49 of the main body case 3 to an oxygen inlet 73 of the controller unit 71; and a tube extending from an unillustrated cannula is connected to an oxygen outlet 77 provided on the
 20 controller unit 71.

Further, when the above-described configuration is employed, a breath detection port 79 (to which a tube branching from the cannula is connected) is

provided separately from the oxygen outlet 77, and the pressure sensor 67 is disposed at the breath detection port 79.

Since the controller unit 71 can be disposed near a patient or any other person, operation is facilitated.

5 Notably, the components which are separated from the main body case 3 and incorporated in the controller unit 71 can be selected freely in consideration of the size of the controller unit 71 and other factors.

EFFECTS OF THE INVENTION

10 According to the first embodiment of the invention, a breath detection port is provided independently of an oxygen outlet. Therefore, through deposition of, for example, a pressure sensor at the breath detection port, breathing cycles can be detected accurately. Thus, breath-synchronized control can be performed properly.

15 According to the invention of the ninth embodiment, when breath-synchronized control is performed, oxygen-enriched gas is supplied at a high flow rate over each inhalation period and at a low flow rate over each exhalation period, whereby the supply of oxygen-enriched gas approximates that of a continuous-flow type to a possible extent. Therefore, a patient hardly feels that something is wrong.

20 Moreover, such breath-synchronized control enables the oxygen enriching apparatus to be used as a large-capacity model (e.g., a 5 liter model), while providing advantages of a small-capacity model such as a 3 liter model.

This application is based on Japanese Patent Application No. 2000-287109 filed September 21, 2000, the disclosure of which is incorporated herein by reference in its entirety.

FIG. 26B